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# An Analysis of the Potential Risk Exposure to Lead (Pb) through Urban Community Gardens

Danielle E. Goveia

*Florida International University*, [dgove002@fiu.edu](mailto:dgove002@fiu.edu)

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FLORIDA INTERNATIONAL UNIVERSITY

Miami, Florida

AN ANALYSIS OF THE POTENTIAL RISK EXPOSURE TO  
LEAD (Pb) THROUGH URBAN COMMUNITY GARDENS

A thesis submitted in partial fulfillment of the

requirements for the degree of

MASTER OF SCIENCE

in

ENVIRONMENTAL STUDIES

by

Danielle E. Goveia

2013

To: Dean Kenneth G. Furton  
College of Arts and Sciences

This thesis, written by Danielle E. Goveia, and entitled An Analysis of the Potential Risk Exposure to Lead (Pb) through Urban Community Gardens, having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this thesis and recommend that it be approved.

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Leonard J. Scinto

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Stewart Reed

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Krishnaswamy Jayachandran, Major Professor

Date of Defense: March 29, 2013

The thesis of Danielle E. Goveia is approved.

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Dean Kenneth G. Furton  
College of Arts and Sciences

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Dean Lakshmi N. Reddi  
University Graduate School

Florida International University, 2013

## DEDICATION

I would like to dedicate this thesis to my father, Guy Goveia. Thank you for always pushing me to fulfill my dreams, reminding me that I can accomplish anything as long as I work hard. Thank you for reminding me every time it seemed too much, to take it one day at a time. Thank you for encouraging me to take the time to enjoy life and all that it has to offer. Thank you for your unconditional love and support, because without you, I would never be where I am today.

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ABSTRACT OF THE THESIS  
AN ANALYSIS OF THE POTENTIAL RISK EXPOSURE TO LEAD (Pb)  
THROUGH URBAN COMMUNITY GARDENS

by

Danielle E. Goveia

Florida International University, 2013

Miami, Florida

Professor Krishnaswamy Jayachandran, Major Professor

Community gardening in cities is increasing, driven by social interaction and food security. City soils are sinks for heavy metals; including neurotoxic lead (Pb). Exposure routes are primarily through inhalation/ingestion of soil, or second by ingestion of plants that have accumulated Pb. This research evaluates soil at three Liberty City, Florida sites estimating risk of Pb exposure through primary and secondary pathways.

Soil cores were collected from Liberty City, and red Malabar spinach (*Basella rubra*) was grown in Pb soil treatments in a greenhouse. Total soil Pb levels and plant tissues were measured after acid digestion, by ICP-OES. In Liberty City, two sites had hotspots with areas of elevated soil Pb levels. Plants grown on Pb contaminated soil all accumulated statistically significant Pb concentrations. Therefore, there is a potential risk of Pb exposure to residents in Liberty City by exposure in hotspot sites through both the primary and secondary pathways.

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## **CHAPTER I: Introduction**

Urban ecosystems are some of the most influential and dynamic ecosystems on the planet, with approximately 50% of the world population currently residing within cities (U.S. Environmental Protection Agency, 2005). While a small percentage of the planet's land is dedicated to cities, given the increasing global population, the number of cities and the density within cities is likely to increase. Therefore, it is extremely important to monitor and assess the health of urban ecosystems to ensure a high quality of life for humans and species that depend on ecosystem services provided in urban environments. One aspect of this assessment is monitoring for toxic heavy metal contaminants, such as lead (Pb), within city soils. The total heavy metal concentration in soils can be used as an indicator of environmental quality within urban areas, but the severity of pollution also depends on the ability of those metals to move through the environment (Morton-Bermea et al., 2009).

Assessment is even more important when urban gardening is practiced socially and promoted or relied upon as a food source. Lead (Pb) is consumed by inhalation or ingestion of contaminated soil particles, or by consumption of foods grown on contaminated soils, which have bioaccumulated Pb in their tissues (Sharma et al., 2008; Zia et al., 2011; Pandey et al., 2012). Exposure to Pb from soil contamination is an environmental justice issue, since it has been observed those affected typically live in urban areas, which include a large portion of lower socioeconomic and minority communities (Clark et al., 2006).

Monitoring the soil can provide an early warning system for the toxic effects of Pb contamination. The importance of heavy metals in soil ecology is closely related to

human and environmental health, as a consequence of the potential for transference through the ecosystem (Morton-Bermea et al., 2009). If a problem is diagnosed early, multiple management options exist for remediation and prevention of recontamination events. Ultimately such a monitoring program would help improve the quality of life within the ecosystem, and allow for continued sustainable growth of cities to accommodate the growing global population.

This research targets surveying for lead (Pb) contamination within Liberty City, Florida. Soil core samples from three sites within Liberty City were collected and analyzed for soil parameters associated with Pb sorption to soil, as well as soil Pb concentrations. A greenhouse study was conducted, using a spinach-like species commonly grown within South Florida and most likely to be included in a home or urban garden. The experimental species used is red Malabar spinach (*Basella rubra*). It is known for having a high heat tolerance, making it a useful garden species to be grown in South Florida. By analyzing the edible parts of each plant for Pb, the secondary risk of Pb exposure can be quantified and analyzed.

### *Urban Ecosystems*

Urban ecosystems are some of the most dynamic ecosystems on our planet, with the number of urban ecosystems significantly increasing with the growth and expansion of cities. Urban areas contain a wide variety of species that define the ecosystem (U.S. Environmental Protection Agency, 2005). However, it is humans and their activities that dominate urban ecosystems, and these human-environment interactions are extensive (Wong and Li, 2004; U.S. Environmental Protection Agency, 2005). Currently, between

forty-five and fifty percent of the world population resides within cities, and this percentage is expected to surpass sixty percent by 2030 (Wong and Li, 2004; U.S. Environmental Protection Agency, 2005). The amount of land that is dedicated to these urban areas has increased, and is currently estimated to be 2.8% of the world's land area (U.S. Environmental Protection Agency, 2005).

Urban ecosystems provide their own unique ecosystem services, which have a significant effect on the overall functioning of our planet. These services include: provision, regulation, and culture, which are necessary for societal interaction and development (U.S. Environmental Protection Agency, 2005). By recognizing these urban ecosystem services and learning how to integrate them into our daily routines, communities can reduce their use of energy and increase efficiency, and improve quality of life (Bartens et al., 2012). Free ecosystem services include storm water and pollution reduction as well as water quality improvement and protection (Bartens et al., 2012). These services are compromised however, when large amounts of contamination exist in the urban soils. A surprising level of biological activity has been observed within urban ecosystems, and urban soils have a surprising capacity to support plant growth as well as soil fauna (Bartens et al., 2012). Coupled with the global growing urban population, it is becoming more important to understand environmental quality and the associations with environmental and human health (Wong and Li, 2004). Therefore, there is a pressing need to maintain the environment within urban areas to supply ecosystem services on local, regional, national, and international scales (Su et al., 2010).

## *Urban Community Gardens*

It has become apparent that the well being of human communities are linked to the well being of the overall environment (Okvat and Zautra, 2011). One of the most important aspects of urban life is the resurgence of urban agriculture. Community gardens can be described as plots of land that can be used by different families, who live typically in urban environments, to grow food (Okvat and Zautra, 2011). These community garden structures are bottom-up collaborative efforts by residents interested in growing food for a variety of reasons. Historically, community gardens were in response to a large crisis, for example, the Victory Gardens grown during World War II (Okvat and Zautra, 2011). The increase in community garden projects today has not been seen since the Victory Gardens of the 1940s (Bartens et al., 2012). Shifts in industry, economy and population, as well as the degradation of quality of life in inner city areas has encouraged people towards this resurgence of creating community gardens. By the mid-1990s, over one million people were involved throughout the United States in an estimated 15,000 gardens (Okvat and Zautra, 2011). Through their rising popularity in cities, urban gardens promote increased societal interaction (Bartens et al., 2012). Typically the mixture in ages and cultures that participate in community gardening projects create a more resilient urban community and help to facilitate a community's recovery after a sudden crisis such as a natural disaster (Okvat and Zautra, 2011). The mixture of older and younger participants allow for different dynamics, such as older gardeners bringing more knowledge and experience, and younger gardeners performing more of the physical labor (Okvat and Zautra, 2011). Community gardens within urban areas have frequently been shown to have a negative correlation with local crime rates

(Armstrong, 2000). Residents have shown support in some urban neighborhoods, witnessed by lack of vandalism in community gardens compared to other areas around the city (Armstrong, 2000).

Urban gardens increase food security, which is important because of rising food costs (Bartens et al., 2012). Gardening projects have been estimated to save between \$50 and \$250 in annual food costs for those participating and growing their own food (Armstrong, 2000). Community gardens also promote healthy eating habits. Fruit and vegetable consumption is essential for a healthy lifestyle and a mitigating factor for chronic diseases. However, only a small percentage of the population eats the recommended amounts (Litt et al., 2011). In the United States, only approximately 20% of the population eats fruits and vegetables five times per day (Carney et al., 2012). One study by Carney et al. (2012) showed a fruit and vegetable intake increase among people participating in gardening projects, with consumption rates of four times more fruits and vegetables in adults and three times more in children. Many of the families were also pleased they were growing vegetables they knew contained no pesticides (Carney et al., 2012).

Urban gardens could also assist in the effort to contribute to climate change mitigation through direct and indirect pathways. Direct pathways include greenhouse gas mitigation and composting kitchen scraps, while indirect pathways include teaching people about climate change and educating how individual food choices can impact climate (Okvat and Zautra, 2011). Other environmental benefits from community gardens are creation of habitats for urban species, increases in biodiversity, and reduction of heat island effects (Okvat and Zautra, 2011).

Whether the garden is grown privately or in a larger community setting, the cost of testing prevents most gardeners from having their soils tested for contaminants (Bartens et al., 2012). For example, MACS Lab, Inc. located in Grass Valley, California, will test soil samples sent to them for heavy metal contamination. The cost is \$37.40 per sample testing for one heavy metal, and costs increase depending on how many samples need to be tested, and how many metals are tested for. There is a cost of up to \$150.00 per sample to test for 17 different heavy metals, including arsenic (As), lead (Pb), and mercury (Hg) (MACS Lab, Inc.). A problem with urban gardening is that if the soil is contaminated, there is a potential for adverse health effects from consuming crops grown in the soils (Bartens et al., 2012).

#### *Negative Effects of Urban Ecosystems*

While urban areas are extremely important for societal development, there are many negative effects associated with cities. Various pressures have limited the ability of urban ecosystems to maintain sustainable development, without significant administrative decisions and oversight. For example, the anthropogenic impact on air pollution in the form of harmful emissions from factories and vehicle emissions is one of the largest concerns worldwide. Atmospheric deposition of heavy metals is recognized as an important source of heavy metals found in soils (Pandey et al., 2012).

One management approach to ecosystem deterioration is to use various methods and indicators to analyze the health of the urban ecosystem. This approach includes attempting to measure changes in human and societal well being, as well as estimating the integrity of the natural ecosystems within an urban area (Su et al., 2010).

Many toxic substances, including heavy metals, have been the source of environmental problems occurring within urban areas. Heavy metals are released into the environment through the burning of fossil fuels, mining, smelting, discharging industrial, agricultural and domestic waste, and by deliberate application through the use of pesticides (Duffus, 1980). These heavy metals can persist and accumulate, since they are not removed rapidly, and are not detoxified by various metabolic activities within the natural environment (Duffus, 1980). People who reside in urban areas with a population over one million have been observed to have higher blood Pb concentrations than urban areas with populations less than one million, which also have higher blood Pb concentrations than residents in rural areas (Gasana et al., 2006).

### *Environmental Justice*

Heavy metal contamination in urban areas can be an environmental justice issue. Literature has suggested residents within lower socioeconomic neighborhoods suffer from substandard health outcomes compared to richer neighborhoods (Gasana et al., 2006). These residents are exposed to close proximity to traffic within inner city neighborhoods, and the related effects of air pollution and lower quality housing impacts on the health of residents, which tend to be minority communities. Lower quality housing can result in a variety of health problems, including lead (Pb) poisoning for those living in the home, especially children (Gasana et al., 2006). For example, children with elevated blood Pb levels are more likely to be poor, African American, and live in metropolitan cities. They are exposed to Pb through peeling or flaking paint in older homes and Pb contaminated soil that enters households as dust. The Center for Disease

Control (CDC) has stated that poverty is a risk factor associated with Pb poisoning in children (Gasana et al., 2006). In Miami-Dade County, Florida, 25% of all residents are children, and 25% of those children live in poverty.

### *Lead (Pb)*

Lead (Pb) is an element widely distributed within the earth's crust and normally occurs in soil at a range of 10 to 50 mg kg<sup>-1</sup> (Stehouwer and Macneal, 1999). However, most problems concerning Pb arise from emissions caused by human use that release this toxic heavy metal into the environment (Duffus, 1980). Lead (Pb) is acknowledged as one of the most frequently encountered heavy metals in polluted environments (Xiong, 1998). Human activity can increase soil Pb concentrations to 150 to 10,000 mg kg<sup>-1</sup> (Stehouwer and Macneal, 1999). Many practices result in the discharge of toxic fumes and dust, such as: the smelting of Pb, the manufacture of pesticides, insecticides, paint, and gasoline containing fuel additives, sewage sludge, mining practices, and from shooting ranges (Duffus, 1980; Xiong, 1998; Siegel, 2002; Zia et al., 2011; Ming et al., 2012). The use of Pb in paints and gasoline has been phased out, but this Pb still persists in soil and water (Clark et al., 2006). The United States banned the use of lead (Pb)-based paint in 1978 and Pb as a gasoline additive in 1986, however both had been used since the 1920s (Gasana et al., 2006). Nationally, it is estimated that the use and disposal of Pb additives in paint and gasoline accounted for about twelve million tons of Pb (Mielke et al., 2008). The prolonged uses, as well as residual wastes put into the environment, have left harmful residues (Gasana et al., 2006).



Lead (Pb) is a neurotoxin, and exposure can cause a lifetime of health risks. Besides neurological defects, Pb can cause anemia as well as comas (Wong and Li, 2004). The exposure risk is higher for children and pregnant women than for adults; however, everyone can experience the effects of Pb poisoning (Mielke et al., 2008; Clark et al., 2006). In children, Pb poses a particular threat because it inhibits their growth and development (Clark et al., 2006). Children are more disposed to Pb poisoning and toxicity than adults because they have more hand to mouth behaviors (Gasana et al., 2006). Children's digestive systems absorb Pb easier than adult digestive systems. A child's central nervous system is still developing, and is more vulnerable to the neurotoxic properties of Pb (Gasana et al., 2006). According to the Joint Executive Council on Food Additives, a collaborative effort between the World Health Organization and the Food and Agriculture Organization, the tolerable daily intake of Pb is 3.5 micrograms per kilogram body weight per day. When the figure is adjusted for a child's weight, that equals about 42 to 70 micrograms per day; any concentration higher would likely trigger health concerns (Clark et al., 2008). According to Ljung et al. (2006), 100 mg of soil per day is ingested by hand to mouth activity in children aged one through six (Clark et al., 2008). Given that statistic, together with the likelihood of contamination events within urban cities, Pb poisoning is a significant concern.

It was estimated that in 2002 the cost of Pb poisoning within the United States was about 2.2% of all healthcare costs; about \$43.4 billion (Mielke et al., 2008). These costs include direct treatment, as well as special education for children and reduced lifetime earning ability from impairments caused. There are also various societal problems correlated with elevated levels of Pb exposure. Violent crime, diabetes, and

unwanted pregnancies have additional social, medical and psychological impacts and costs for members of the community that correlate to Pb toxicity (Mielke et al., 2008).

In Miami-Dade County, Florida, several communities within the inner city have a large proportion of children less than 6 years old with Pb poisoning, compared to the same age group in other areas (Gasana et al., 2006). Relative to Miami-Dade County, the area of Liberty City, the site for this thesis research, has approximately 23% of all childhood Pb poisoning cases, despite having only 8% of children less than 6 years old. Over 60% of all the Pb poisoning cases in children are reported within low socioeconomic communities such as Liberty City, North Miami, Hialeah, Miami Lakes, Little Havana and Little Haiti (Gasana et al., 2006). Housing in this area is older, with approximately 20% built before 1950. Older homes are more likely to contain substances such as lead (Pb)-based paints (Gasana et al., 2006).

The climate of south Florida contributes to the likelihood of exposure to Pb from contamination in the environment. In South Florida, windows and doors of homes are kept open throughout the year (Gasana et al., 2006). Many older homes in poorer communities lack air conditioning, increasing the need to keep the doors and windows open for ventilation. Since these homes are small and surrounded by uncovered dirt yards, soil contaminated with Pb is more likely to enter the home and contribute to household dust (Gasana et al., 2006). An estimated two-thirds of indoor house dust can be attributed to close exterior sources, leading to the belief that a majority of indoor exposure to Pb dust occurs because of contaminated soil (Clark et al., 2008). This fact contributes to the frequent cases of Pb poisoning seen among children in the community. The Florida Childhood Lead Poisoning Prevention Program has identified lead (Pb)-

contaminated soil and household dust as a major source for Lead (Pb) poisoning within the State of Florida (Hopkins et al., 1995; Gasana et al., 2006).

### *Soil Lead (Pb)*

Within urban areas, the soil is an important sink for Pb in the environment, thus a major site for exposure (Wong and Li, 2004; Clark et al., 2006). Though there are multiple direct exposure pathways for Pb, ingestion of soil is considered a higher concern compared with dermal absorption and respiratory pathways (Zia et al., 2011). A second pathway of importance is through ingestion of food grown on contaminated soil. The secondary pathway is an even larger threat when urban gardening is an important part of community life, and a significant food source for urban residents (Clark et al., 2006; Clark et al., 2008).

After Pb enters the body through inhalation or ingestion, the initial receptor is the blood, which absorbs and distributes it throughout the body making it available to other tissues (Clark et al., 2006). For this reason, Pb affects nearly every system within the body (Gasana et al., 2006). Lead (Pb) is teratogenic, carcinogenic, toxic at low doses, and known to readily accumulate within organs (Wong and Li, 2004). Background levels for Pb in blood are estimated to be 0.016 micrograms per deciliter (Wong and Li, 2004). The CDC has stated 10 micrograms Pb per deciliter is the blood lead (Pb) limit (BLL), after which detrimental neurological effects will be evident (Clark et al., 2008). However, studies have reported that detrimental neurological effects were observed at blood Pb levels less than 10 micrograms per deciliter (Wong and Li, 2004; Clark et al., 2008). It has been argued there is no level of Pb within the body that could be considered safe.

According to the National Research Council (NRC), even minimal exposure to Pb could produce small effects with regards to human health (Gasana et al., 2006). The NRC also presented evidence that Pb in blood at 5 micrograms per deciliter could produce symptoms such as attention deficit disorders and hearing loss in children (Gasana et al., 2006). Therefore the current blood Pb limit of 10 micrograms per deciliter is not adequately protecting children from Pb toxicity, and it is unsure if there is an effective threshold dose for the adverse effects of Pb.

The distribution of Pb and other heavy metals in soil is dependent on different soil properties including: texture, organic matter content, clay mineral content, aluminum, iron and manganese oxides, pH, and reduction/oxidation potential of the soil (Ming et al., 2012). Lead (Pb) tends to form strong bonds with particles in the topsoil when contamination is from air-borne emissions (Ming et al., 2012). Ming, et al. (2012) demonstrated that Pb tended to preferentially bond with soils having a high pH value, therefore the plant available fraction in soil will decrease as soil pH increases (Zia et al., 2011; Ming et al., 2012).

Lead (Pb) is mostly found in the organic matter and carbonate fractions of soil. The soil's toxicity will depend on the how long the contamination has been present, the local climate, hydrology of the area, and the nature of the Pb containing compounds present (Ming et al., 2012). Clark et al. (2008), found that Pb contamination within soil used for gardening is homogenously distributed, and there is no concentration gradient as a function of distance from the residential structure or the road since the soil in that area is mixed by tilling (Clark et al., 2008). The study also found evidence of an inverse relationship between Pb concentration and particle size in the clay fraction. When the

clay particle size was less than 100 micrometers, there were elevated concentrations of Pb. A small particle size is considered wind transferable (Clark et al., 2008). If high Pb concentrations exist where particle size is small, and those particles are wind transferable, a mechanism exists for transport, which can lead to new contamination events, or recontamination of remediated sites. The study also found that larger sizes, up to a diameter of 50 micrometers, are more likely to adhere to hands, and therefore are the major contributor to ingestion by accidentally placing hands in or near the mouth, after working in contaminated soils (Clark et al., 2008). Soil moisture is another characteristic influencing Pb concentrations and thus blood Pb levels. Soil moisture is directly related to the suspension of Pb dust particles, therefore during periods of low soil moisture, fewer colloidal sized particles are suspended in soil solution and more Pb dust particles are subject to erode. During periods of higher soil moisture Pb dust particles are less likely to become wind bourn (Mielke et al., 2008). Ageing of contaminated soil, however, has been observed to substantially influence the availability and erode ability of contaminants. The longer the contamination has been present in soil, the more time it has had to form strong bonds to various sites within soil, such as organic matter, making the Pb less available (Mielke et al., 2008). The bioavailable portion of the metal within the soil is defined as the fraction of the total metal present that is either available or can be made available for absorption by plants or organisms (Ahmad et al., 2012). The bioaccessible portion of the metal is the fraction of the total metal present in the ingested soil, sediment or water that can be released during digestion or biotransformation within an organism (Ahmad et al., 2012). Generally the bioavailability/bioaccessibility of Pb is estimated to be between 30% and 50% within the soil (Clark et al., 2008). The

bioaccessible portion of Pb can be equal or greater than the bioavailable portion (Clark et al., 2008). A study by Mielke et al. (2012) did show soil that had been aged for 3 months had Pb in a form that may have been bioavailable when in the presence of acids, such as gastric acids (Mielke et al., 2008). Therefore if soil were ingested, there would still exist the risk of Pb poisoning.

Within soil, the transformation of Pb by weathering and oxidation increases the solubility and availability in the surrounding environment, making it a larger threat (Ahmad et al., 2012). Lead (Pb) has the ability to readily accumulate in soils and sediments, and it may easily be absorbed or accumulated in the bodies of plants and animals when altered within soils to available forms (Ahmad et al., 2012). Lead (Pb) is one of the heavy metals with no known biological function in organisms (Xiong, 1998; Wong and Li, 2004). The impact of Pb on organisms within the soil, such as plants and bacteria, results in a variety of Pb toxicity symptoms. For example, lettuce exhibits reduced root and shoot elongation, and bacteria, such as *V. fischeri*, experience disturbed metabolism (Schreck et al., 2011). After long-term exposure, the metal bioavailability in the soil does decrease, and thus so does ecotoxicity (Schreck et al., 2011). Assessing a combination of these factors help to determine how much Pb in soil is available for uptake by plants grown on that soil. Understanding these mechanisms can serve as a way to avoid the secondary form of Pb poisoning: from eating vegetables grown in contaminated soil.

Much research has demonstrated that Pb is an extremely persistent heavy metal, which can readily accumulate in crops and dietary vegetables (Pandey et al., 2012). The uptake and bioaccumulation of Pb from vegetables, is influenced by a number of factors.

These factors include: climate, atmospheric depositions, Pb concentration in the soil, characteristics of soil on which vegetables are grown, and plant maturity at the time of harvest (Sharma et al., 2008). When a soil is heavily contaminated with Pb, plants take up and accumulate the metal throughout their root system (Xiong, 1998). If the air is heavily polluted, plant leaves will trap and accumulate heavy metals, resulting in a higher concentration of Pb in the aboveground plant tissue compared to the root system (Xiong, 1998).

Atmospheric deposition of has been recognized as one especially important source of Pb contamination for soils, including large agricultural systems (Pandey et al., 2012). It is now widely believed that atmospheric deposition is one of the principal sources of Pb contamination for crops and vegetables grown within urban areas (Pandey et al., 2012). Particulate matter released from the metal industry, such as secondary smelters that recycle batteries, release significant amounts of fine Pb enriched particles into the air (Schreck et al., 2011). These particles transfer from the atmosphere to the soil, soil solution and then to surface or subsurface waters by runoff or erosion (Schreck et al., 2011). The impact depends on the interactions between soil and particulate matter, such as complexation, fixation, dissolution, mobility and bioaccessibility (Schreck et al., 2011). Atmospheric deposition onto crops can allow the Pb to either be absorbed directly from the plant surfaces, or indirectly through deposition onto the soil followed by absorption by the roots. It can be a significant route for exposure if vegetables, exposed to atmospheric deposition of Pb particles, are not washed properly. A study done by Clark et al. (2008) found that vegetables washed in the kitchen-mimicking style had

concentrations of Pb nearly double those that had been washed to laboratory quality (Clark et al., 2008).

### *Lead (Pb) and Plants*

Plant uptake of soil Pb is not considered as problematic as uptake of other heavy metals, since tight binding of Pb in the soil and plant material account for the low mobility of this metal in soils and plants (Xiong, 1998). Lead (Pb) is among one of the more immobile heavy metals from the soil to the shoot (Xiong, 1998). High Pb concentrations are more likely to accumulate in the tissue of leafy vegetables and on the surface of root crops than in fruiting structures (Rosen, 2010). Still, the surface of fruit can become contaminated with Pb from dust from contaminated soil.

It is possible for vegetables grown in urban or industrial areas to accumulate high levels of Pb and other heavy metals originating not only from soil and atmospheric depositions, but also from water sources. Areas that have had a long-term reliance on treated or untreated wastewater for irrigation typically experience heightened levels of Pb. Similarly, using untreated manures, sewage sludge, and pesticides to increase crop yield, could increase crop uptake of Pb when the Pb accumulates within the soil (Sharma et al., 2008).

Plants can accumulate Pb via the root and shoot, and those concentrations will be significantly related to the Pb levels in the environment (Xiong, 1998). It has been reported that kale, ryegrass, spinach and other leafy vegetables accumulate high amounts of air-borne heavy metals, including Pb (Siegel, 2002; Pandey et al., 2012). Pandey et al. (2012) tested vegetables with different edible parts grown on Pb contaminated soil. They



reported that maximum Pb accumulation was found in the leafy vegetable spinach, followed by tomato fruit and lastly by edible roots like radish (Pandey et al., 2012). However, all three vegetables were observed to contain concentrations that would significantly add to the total heavy metal intake of a person consuming them, leading to the negative health effects from consuming such elements (Pandey et al., 2012).

Some plant species can experience toxic effects from being exposed to excessive amount of Pb. These effects include a decrease in seed germination, root elongation and biomass accumulation, inhibition of chlorophyll biosynthesis, as well as cell disturbance and chromosome lesion (Xiong, 1998). Some plant species are known to be hyperaccumulators, which have the ability to accumulate an unusually high concentration of heavy metals without being dramatically impacted in growth and development (Xiong, 1998).

### *Research Objectives*

As a result of this thesis research, a risk determination will be estimated for exposure to Pb, through both the primary and secondary pathways, for residents of Liberty City. These two situations account for the primary and secondary pathways residents in urban areas are exposed Pb and potentially the toxicity associated with elevated blood Pb levels.

The research is intended to:

1. Characterize the soil at three sites within Liberty City, Florida.
2. Evaluate the three study sites for soil Pb contamination and compare them with a control soil from an organic farm in Homestead, Florida.

3. Determine the bioavailability of Pb within the soil by growing plants in contaminated soil from Liberty City and an artificially contaminated soil, and analyzing how much is accumulated within the edible parts of the plant.
4. Estimate what risk exists within Liberty City for Pb poisoning associated with contaminated soil.

### *Hypotheses*

The soils in Liberty City, Florida will contain substantial amounts of Pb, and edible plants grown on that soil will absorb Pb, though the concentration will be significantly less than the total concentration of the soil. The potential primary pathway for Pb toxicity will be through direct contact with the soil, and the potential secondary pathway will be through eating edible plants grown within contaminated soil. This thesis research will test the following four hypotheses:

1. The soil from each of the three sites in Liberty City will be of similar composition.
2. The soil from the three study sites will have a significantly higher concentration of Pb when compared to the control organic soil.
3. The concentration of Pb that is bioavailable from the soil will be less than the total concentration, and thus the concentration of Pb in plants grown in that soil will be less than the total soil-Pb concentration.
4. There will be a risk of Pb poisoning to residents, especially children, living in Liberty City, due to contaminated soil.

### *Study Importance*

There exists a need to understand what contaminants are present within urban soils, especially because of the already high, and growing, volume of people residing within urban areas. Since a large percentage of that population is typically from poor or minority communities, the environmental justice aspect of anthropogenic contamination events needs to be further understood and better managed. Residents should be able to understand the risks associated with their homes and backyards, where both adults and children alike can be exposed to harmful toxic agents. They also should be educated in ways to avoid exposure and provided options for safely practicing the social fulfillment of having an urban garden.

## **CHAPTER II: Materials and Methods**

### *Study Site and Sample Collection for Soil Analysis*

The site selected for this study was the neighborhood of Liberty City, located in Miami-Dade County, Florida. The boundaries for Liberty City are Northwest 79<sup>th</sup> Street to the north, Northwest 27<sup>th</sup> Avenue to the west, the Airport Expressway (State Road 112) to the south, and the Interstate 95 (I-95) to the east (Figure 1). According to the 2010 census, the population of the neighborhood is 22,749, 83.89% of the population is African American, and 13.94% of the population is Hispanic (U.S. Census, 2010). The inner city Miami neighborhood was selected because it represents an urban environment with little information available regarding soil Pb levels.

Samples were collected from three sites within Liberty City. The first site was Miami Northwestern Senior High located at 1100 Northwest 71<sup>st</sup> Street, Miami FL 33150. The specific site was selected because Florida International University has a partnership with the high school, and one project as part of that partnership is to develop an organic garden. The proposed site for the organic garden was sampled, as well as the area close to the organic garden site.

The second site selected for sample collection was Olinda Park, located at 2101 Northwest 51<sup>st</sup> Street, Miami FL 33142. The Olinda Park site was selected because there is suspected Pb contamination at the park, according news articles published in the summer of 2011 (Rapado, 2011). Though the park was closed to the public, the fence put up around the park to keep visitors out was cut open, giving neighborhood residents and children access to the park and basketball court, and allowing exposure to the Pb

contaminated soil. The source of the Pb contamination at the park was unknown, as well as the levels of contamination prior to this analysis.

The third site selected for analysis was JG Shamrock/Supreme Service Station located at 6200 Northwest 17<sup>th</sup> Ave, Miami FL 33147. The site was selected because it is a documented brownfield site by Miami-Dade County (U.S. Environmental Protection Agency, 2004). Since it was previously a gas station and is now a vacant open lot with no known plans for development, residents walking or playing in the lot may be exposed to residual chemicals after demolition of the gas station. Lead (Pb) was also a known additive to gasoline, and potentially remains in the soil.

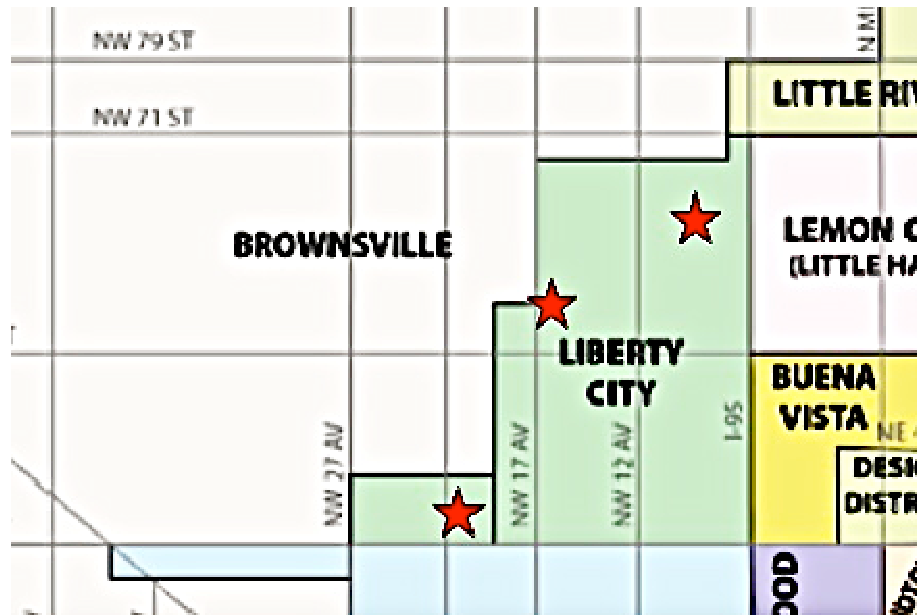


Fig 1. Map of study site including locations of sampling in Liberty City, Florida

All three of the sites will be compared to a control site. The chosen control site is an organic lettuce farm located in Homestead, Florida. The farm is Quality Certification

Services Certified Organic since 2003, and is owned by Tim Rowan. The farm started as a small garden in his backyard in 1989 (Rowan, 1999). The organic farm was selected since it is isolated away from main roadways and thus does not experience heavy traffic, limiting a potential mechanism for soil contamination. The farm only uses organic amendments to the soil. Since Pb has been used as an additive in various pesticides, this avoids that potential for Pb contamination (Duffus, 1980; Xiong, 1998; Siegel, 2002; Zia et al., 2011; Ming et al., 2012).

Soil cores were collected using a 5.7 cm diameter acrylic tube, collecting to a depth of 15 cm. At each site four replicate soil cores from randomly selected locations were collected, accounting for special variability. The samples were then pulverized and sieved using a 2 mm Fisher Scientific sieve and air-dried.

#### *Sample Preparation and Lead (Pb) Analysis*

After soil samples were air-dried and sieved, subsamples from each core were analyzed for total plant nutrient concentrations, and total Pb concentration. Each core was analyzed in triplicate, to get an average. Samples were prepared according to United States EPA Method 3051 for microwave acid digestion with a Milestone Start D microwave digestion system. Known oven-dried equivalent weight of nominally 0.2500 grams of sample was weighed out into each microwave vessel. Using a pipette, 10 mL of 65% nitric acid (HNO<sub>3</sub>) was then added to each vessel. The vessels were placed in the microwave and digested for approximately 30 minutes – 15 minutes to reach the holding temperature of 175 °C, 15 minutes held at a temperature of 175 °C, and then a cool down period of approximately 40 minutes. Vessels were removed from the microwave when

the temperature was cooled to approximately 30 °C. After digestion was completed, samples were emptied out of the vessel and filtered through Whatman No. 1 filter paper, and diluted to 100 mL in a volumetric flask. Flasks were then emptied into labeled 125 mL sample bottles, and stored in a refrigerator at 4 °C until they could be analyzed using a Thermo Scientific iCAP 6000 series Inductive Coupled Plasma Spectrometer (ICP-OES).

#### *Available Nutrient Analysis*

To analyze for available phosphorus, 0.1M sodium bicarbonate ( $\text{NaHCO}_3$ ) extraction (pH = 8.5) was performed in a 1:20 (w:w) ratio (Olsen et al., 1954). A one-quarter teaspoon scoop (approximately one gram of soil) was removed, weighed, and added to 125 mL sample bottles. A 20 mL aliquot of sodium bicarbonate extraction solution was added to each bottle. Bottles were then placed on a shaker table for thirty minutes (38 mm stroke length, 180 strokes  $\text{min}^{-1}$ ). After shaking, the bottles were centrifuged at 1450 G for approximately thirty seconds, and then filtered through Whatman No. 42 filter paper into labeled 125 mL sample bottles. The samples were stored in a refrigerator at 4 °C until they could be analyzed using the ICP-OES.

To analyze for available nutrients, including potassium, sodium, calcium, magnesium, manganese, zinc and copper, the Mehlich 3 extraction procedure was performed in a 1:10 (w:w) ratio (Mehlich, 1984). Two grams of soil were weighed and placed in 125 mL bottles. A 20 mL aliquot of Mehlich 3 extraction solution was added to each bottle. Samples were then placed on a shaker table for five minutes (38 mm stroke length, 180 strokes  $\text{min}^{-1}$ ) and afterwards centrifuged for approximately thirty seconds.

Samples were then filtered through Whatman No. 1 filter paper, stored in labeled 125 mL sample bottles and placed in the refrigerator at 4 °C until they could be analyzed using the ICP-OES.

After all digestions and extractions were complete, a 5-milliliter aliquot of each was placed in a test tube for Inductive Coupled Plasma Spectrophotometer analysis. Each sample was diluted with 5 mL of 10% nitric acid, since nitric acid is the carrier solution in the Inductive Coupled Plasma Spectrophotometer.

### *Soil pH*

The pH was measured using a 1:2 soil:solution slurry (Soil and Plant Analysis Council, Inc., 1999). Samples were allowed to sit for 25 minutes before a pH meter was placed in the slurry. Values were recorded once the reading stabilized.

### *Greenhouse Study*

A greenhouse study was conducted to investigate the bioavailability of Pb present in Liberty City soils. A greenhouse study occurred between December 2012 and February 2013. Before the greenhouse study was conducted, soils from Liberty City were analyzed to determine if they met the criteria for being considered Pb contaminated by the United States Environmental Protection Agency – having a soil Pb concentration of greater than 400 mg/kg (U.S. Environmental Protection Agency, 2012). Soils with total Pb concentrations above 400 mg/kg were used as treatments for the greenhouse study. Since soils from two of the sites met this level of contamination, larger amounts of soil from



Olinda Park and JG Shamrock/Supreme Gas Station were collected in 10-gallon plastic containers to be used for planting.

An additional treatment was created by artificially spiking a potting mixture with lead nitrate at a concentration of 400 mg/L. To create the spiked soil, the potting mixture was aged for approximately one month. The potting mixture was spread out on six shallow plastic trays, each tray holding two pots worth of soil. Lead nitrate solution was prepared by adding 0.8 grams of lead nitrate to a one-liter volumetric flask. The flask was brought up to volume with deionized water and mixed until the lead nitrate was completely dissolved. The lead nitrate solution was then poured into each tray of soil until the soil was saturated. Two liters of lead nitrate solution were required to saturate all six trays. After saturation the soil was allowed to air dry in a dark room for approximately five days at a time, until the soil was no longer moist to the touch. The soil was aged for six wet and dry cycles. The artificial treatment was created to investigate the differences in bioavailability between the unknown Pb forms and origins in the sample soils from Liberty City, and known inorganic Pb from lead nitrate solutions. Since the amount of time the Pb has been in the soil also influences bioavailability, the effect of ageing would be observed, as well, through the addition of the spiked soil treatment. The spiked soil was not intended to recreate field conditions present in Liberty City.

Red Malabar spinach (*Basella rubra*) plants were used to investigate the bioavailability of lead (Pb). The focal plant was selected because of research showing heavy metals have a tendency to accumulate in the edible parts of leafy vegetables (Rosen, 2010). Malabar spinach grows well in warm climates and in a variety of soil conditions (Stephens, 2009).

Seeds were obtained from David's Garden Seeds and Products located in San Antonio, Texas. Seeds were soaked in water overnight before planting. The next day, seeds were planted in one-gallon pots, in the soil treatments. The treatments were as follows: soil from Olinda Park in Liberty City, soil from JG/Shamrock Supreme Service Station, soil spiked with lead nitrate, and a control soil. The control soil was a potting mix obtained from the USDA-ARS Subtropical Horticulture Research Station. The potting mixture consisted of 50% Pinebark, 10% sand, 40% coir pith with 9 pounds dolomite, and 3 pounds MicroMax per cu yd. [6% Ca from calcium carbonate, 3% Mg from magnesium carbonate, 12% S, 0.10% B from sodium borate, 1% Cu from copper sulfate, 17% Fe from ferrous sulfate, 2.5% Mn from manganese sulfate, 0.05% Mo from sodium molybdate, 1.0% Zn from zinc sulfate]. The potting mix was chosen as the control soil, because it was assumed that if people were not planting their garden in the soil already in their yards, they would be purchasing and bringing in potting mixtures. Each soil treatment was homogenized by hand to create a uniform blend for planting. Rockwool was placed on the bottom of each pot to prevent soil from falling out the bottom while being watered. The potting occurred on December 18, 2012.

Each treatment consisted of ten replicates with two seeds planted in each pot. After germination, the pots were thinned to one plant per pot. Which plant to remove was determined by visual assessment for which plant looked healthier and larger. In the event that none of the plants in a pot germinated, the second plant from a pot within the same treatment was transplanted into the empty pot. After the pots were thinned, one tablespoon of 14-14-14 fertilizer was added to each pot and then misted with water to assist dissolving.

Pots were placed in four hydroponic tanks located in the greenhouse at the USDA-ARS station. Hydroponic tanks were used to ensure all plants were watered evenly and consistently with respect to time of day. Each tank had its own 55-gallon drum reservoir, and the tanks filled with water every day at 10am from this reservoir, and began draining at 10:30am. Weeds were pulled from the pots in each treatment when discovered. The plants were visually inspected at least three times a week.

Every Wednesday and Friday, the individual drums containing the water for each hydroponic tank were topped off with fresh water to account for any evaporation and to ensure the tanks had enough water to saturate the pots when the tanks filled. Water from each 55-gallon reservoir was replaced with fresh water every two weeks. Water that had contact with Pb soils was collected and filtered before being released.

Plants were harvested once five large mature leaves were observed in the control, ensuring there would be enough biomass for elemental analysis. At harvest, the entire plant was removed from the pot, so the edible portions of the aboveground tissue and the roots could be analyzed separately for lead (Pb). The entire plant was taken out of the pot and gently washed as thoroughly as possible to remove debris from the roots. Plants were placed in labeled paper bags and oven dried at 50 °C until there was constant weight. After drying the aboveground tissue was cut from the root and each fraction separately weighed. Each portion of the plant was then ground in a mill, and placed in labeled sample bags.

Plant tissue samples were then microwave digested using EPA Procedure 3051, and analyzed using the ICP-OES.

### *Water Treatment*

The water from each treatment where soil contained Pb would itself contain Pb that leached from the soil. The water was stored in a 500-gallon tank and filtered before being released, to ensure no Pb was released back into the environment. There was no commercially available filter for Pb, therefore one had to be built in the lab prior to the greenhouse study. To begin with, a Mehlich 3 extraction was performed to estimate the amount of Pb that would be leach off of the soil during watering. The results of this extraction are shown in the table below (Table 1).

Site		Mehlich 3 extraction for Pb
		mg kg <sup>-1</sup>
Northwestern Senior High	Mean	3.8 ± 1.1
Olinda Park	Mean	36.7 ± 24.5
JG Shamrock/Supreme Gas Station	Mean	14.7 ± 12.7
Control Organic Farm	Mean	3.5 ± 0.1

Table 1. Mehlich 3 extraction results to estimate the amount of Pb that would leach off of soils while watering during the greenhouse experiment

A filter was then constructed using PVC pipe and fittings. The PVC pipe was filled with alternating layers of unbleached sand and Dowex MAC-3 cation exchange resin. The estimation of how much Pb would leach off of the soil was necessary to

calculate and make sure the filter was filled with enough cation exchange resin to absorb all the Pb from the water for the duration of the greenhouse study.

To filter the water, it was pumped out of the individual hydroponic reservoir drums and into a large holding tank. Water was then passed by gravity through a high purity organics filter (D50252; Barnstead-Thermo Scientific) to remove organic compounds followed by the specifically constructed filter to remove Pb. Before any water was released into the environment, the water coming out at the end of the filtration system, and water before filtration was analyzed using the ICP-OES. Analysis showed that before filtration Pb was above the detection level of the ICP and after filtration Pb levels were below the detection level (0.5  $\mu\text{g/L}$ ).



Fig 2. Water filtration system to remove lead (Pb) from the water from hydroponic tanks including holding tank, organics filter and lead (Pb) filter



Fig 3. Close up of organic filter and lead (Pb) filter for water from hydroponic reservoir tanks

### *Statistical Analysis*

Data analysis was conducted using SPSS v. 21 (Chicago, Illinois). Data were first checked for normality using the Shapiro-Wilk test and Normal Q-Q plots. The data for total Pb concentration in soil was found to be non-normal, and required a logarithmic transformation. One-way analysis of variance (ANOVA) was performed to explore differences in Pb concentrations in soil as a function of site. A Welch's ANOVA was

performed since the data sets did not have equal variances. When statistically significant results were obtained at  $p < .05$  level or less, the Games-Howell test was performed because of unequal variances.

The data for the total Pb concentration in the aboveground tissue was found to be non-normal as well and required logarithmic transformation. One-way analysis of variance (ANOVA) was performed to explore differences between Pb concentrations in the aboveground tissue as a function of the soil types in the greenhouse treatments. When statistically significant results were obtained at  $p < .05$  level or less, post-hoc tests were performed using the Tukey test to determine differences.

The data for the total Pb concentration in the root tissue was found to be normal and did not require transformations. One-way analysis of variance (ANOVA) was performed to explore differences between total Pb concentrations in the root tissue as a function of the soil types in the greenhouse treatments. When statistically significant results were obtained at  $p < .05$  level or less, post-hoc tests were performed using the Games-Howell test to determine differences.

Finally, a paired t-test was performed between the Pb concentrations in the aboveground tissue and the Pb concentrations in the root tissue to investigate if the averages of the Pb concentrations would significantly differ by plant pot.

### **CHAPTER III: Results**

#### *Soil Lead (Pb) Analysis*

Results of the soil in the cores from the different sites revealed three cores at Olinda Park and one at JG Shamrock/Supreme Gas Station with concentrations of soil Pb over 400 mg/kg (Fig. 5). However, statistical analysis results showed that there were significant differences between mean soil Pb levels at Northwestern Senior High and Pb levels at JG Shamrock/Supreme Service Station and the control organic farm (Fig. 4). There were no significant differences between the soil Pb levels at Olinda Park and any of the other sites. There was no significant difference between soil Pb at JG Shamrock/Supreme Gas Station and the control organic farm. The statistical analysis also showed a large variance for the Olinda Park and JG Shamrock/Supreme Gas Station sites. This is a result of the fact that there were cores at the site that were over the EPA limit of 400 mg/kg, but there were also cores that fell below that.



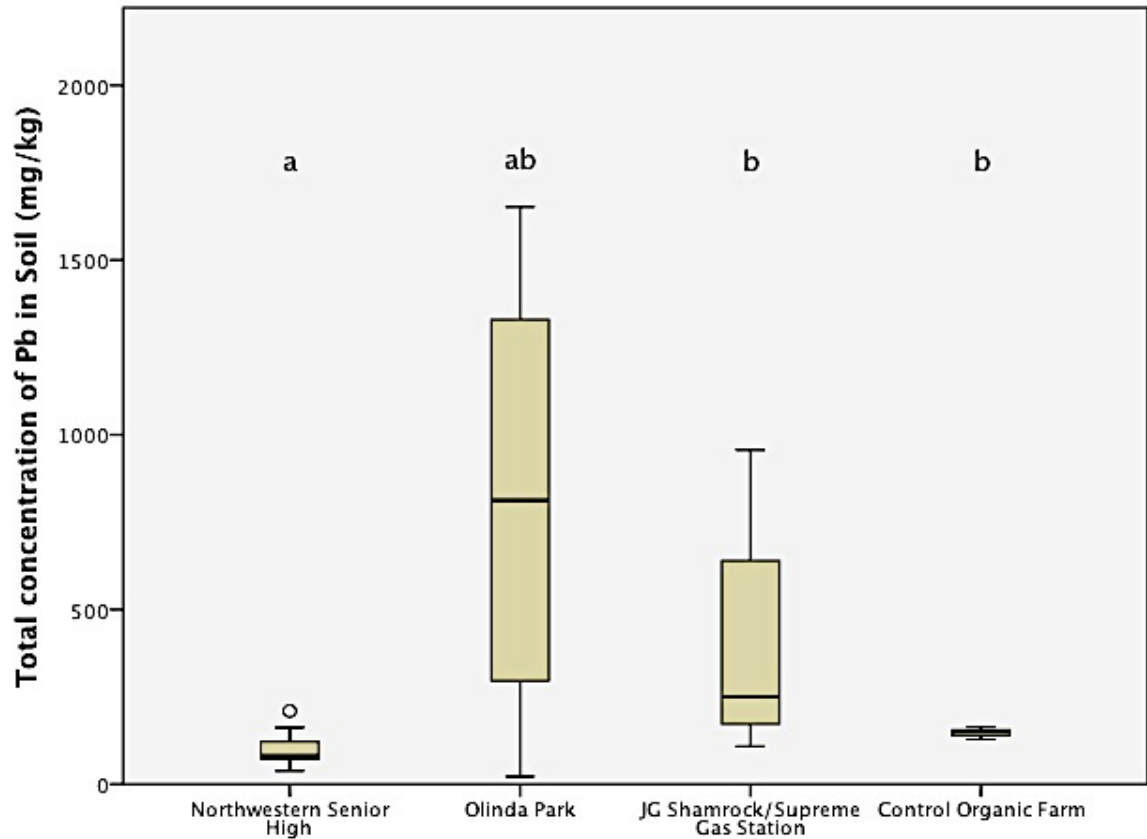


Fig 4. Average total lead (Pb) concentration in soil collected at three study sites in Liberty City, FL and control site in Homestead, FL

At Olinda Park, three soil cores were over the 400 mg/kg soil Pb limit, and at JG Shamrock/Supreme Gas Station one soil core was over the 400 mg/kg soil Pb limit.

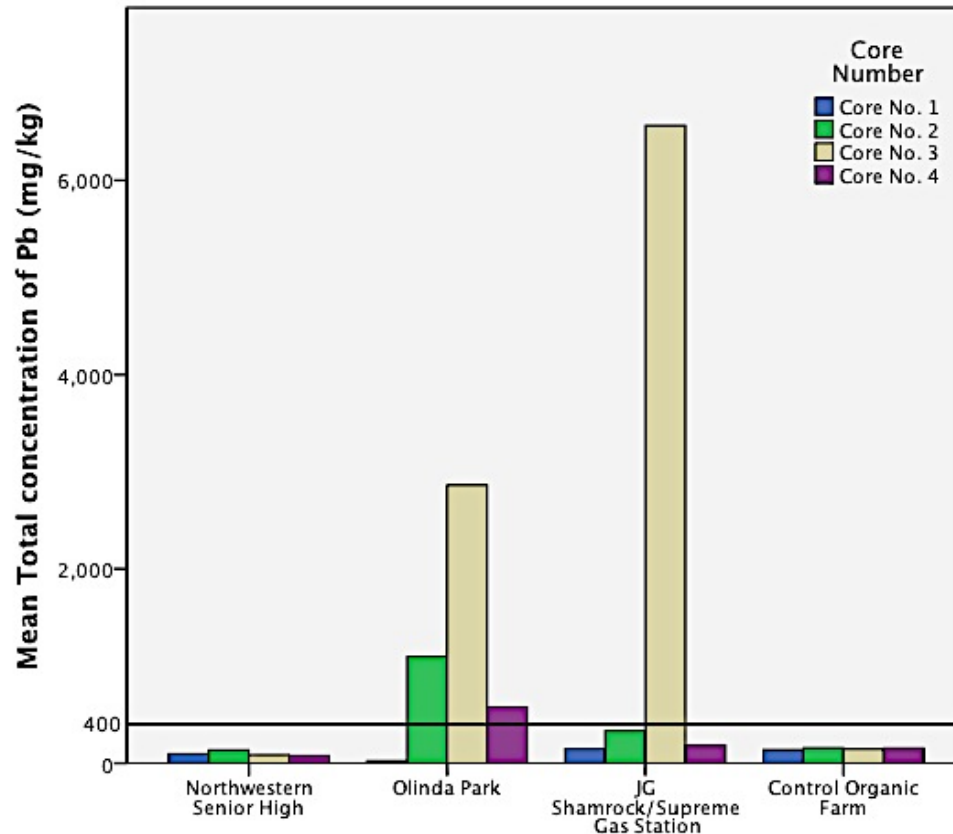


Fig 5. Soil core lead (Pb) concentrations from the four cores collected at three sites in Liberty City, FL and control site in Homestead, FL

Since the ANOVA is comparing average levels from the entire site, the lower soil core Pb and hotspot soil core Pb results made averages more comparable, influencing the statistical results. Further testing and soil analysis would be needed at both sites to more clearly identify the location and scope of the hot spots since the sampling design did not account for hotspots. These results were different than what was expected, based on research such as the Clark et al. study in 2012 that found Pb was homogeneously distributed in residential areas. The results for the soil in this study showed the Pb to be heterogeneously distributed, with areas of low and high concentration occurring in areas

a short distance from each other. Therefore, it would be possible to sample a garden plot, such as the garden plot sampled at the Northwestern Senior High School, and miss an area of high concentration. A sampling method that would better serve sites such as the ones in Liberty City could be the EPA Soil Screening Guide sampling method for suspected contaminated sites. In this method, the sites are divided into exposure areas, usually around 0.5 acres or less. Those exposure areas are then divided into a grid, and 6 subsamples are taken from each grid to make a composite sample for the area (U.S. Environmental Protection Agency, 1996).

#### *Soil Nutrient Analysis*

In order to characterize the soil located at each site, a Mehlich 3 extraction was conducted to describe the available potassium, sodium, calcium, magnesium, manganese, zinc and copper. An Olsen et al. sodium bicarbonate extraction was used to describe available phosphorus at each site. The results of the extractions are shown in the tables below (Table 2 and Table 3). These tables give an overview of the available macronutrients (K, Ca, Mg and P), micronutrients (Cu, Mn, and Zn), and sodium at each site, as well as the average pH of the soil at each site.

Site		Nutrient concentration				
		Mehlich 3 extraction of Ca	Mehlich 3 extraction of Cu	Mehlich 3 extraction of K	Mehlich 3 extraction of Mg	Mehlich 3 extraction of Mn
		----- mg kg <sup>-1</sup> -----				
Northwestern Senior High	Mean	8704.0 ± 2156.5	0.7 ± 0.1	20.8 ± 5.7	63.4 ± 14.5	1.9 ± 0.3
Olinda Park	Mean	7842.6 ± 3304.7	5.8 ± 3.1	114.1 ± 62.6	247.3 ± 113.0	3.2 ± 1.0
JG Shamrock/Supreme Gas Station	Mean	12364.5 ± 1315.2	1.0 ± 0.4	12.9 ± 3.8	82.2 ± 22.7	2.0 ± 0.6
Control Organic Farm	Mean	15277.1 ± 490.1	2.8 ± 0.3	158.5 ± 41.7	222.4 ± 15.1	15.5 ± 0.6

Table 2. Concentrations of available nutrients from three sites in Liberty City, FL and control site in Homestead, FL

Site		Nutrient Concentration			pH
		Mehlich 3 extraction of Na	Mehlich 3 extraction of Zn	Olsen Extraction of P	
		----- mg kg <sup>-1</sup> -----			
Northwestern Senior High	Mean	209.0 ± 8.2	10.5 ± 1.9	9.4 ± 5.4	6.46
Olinda Park	Mean	254.5 ± 52.2	45.4 ± 21.0	18.7 ± 11.4	7.81
JG Shamrock/Supreme Gas Station	Mean	214.3 ± 13.1	21.9 ± 13.6	11.0 ± 7.7	7.93
Control Organic Farm	Mean	223.6 ± 4.5	18.0 ± 2.5	69.8 ± 6.1	7.39

Table 3. Concentrations of available nutrients and average pH at three sites in Liberty City, FL and control site in Homestead, FL

It was originally hypothesized the sites located in Liberty City would be similar in composition, and the control organic farm would contain higher amounts of nutrients. This was not always the case. For the macronutrients Ca, K, and P the organic farm did have the highest amounts, but for Mg Olinda Park had the highest values. For the micronutrients, Olinda Park had the most Cu and Zn, however the organic farm had the highest values for Mn. This information would also be useful for the residents who wish to form a garden at one of the sites, such as the garden project at Northwestern Senior High School, to know what nutrients are already in the soil before adding amendments.

### *Seed Germination*

A plant growth study was conducted on the two most contaminated soils based on the results of the Pb soil analysis: Olinda Park and JG Shamrock/Supreme Gas Station. The two other treatments used were a lead nitrate spiked soil (at a concentration of 400 mg/kg) and a control potting mix. Seed germination rates (# seeds germinated/20 total planted) of red Malabar spinach (*Basella rubra*) were highest in the JG Shamrock/Supreme Gas Station at 85% followed by 80% for the control and 65% and 60% for Olinda Park and lead nitrate spiked soil, respectively (Fig. 6). Every pot using the JG Shamrock/Supreme Gas Station soil had growing in it at least one spinach plant. In the lead nitrate spiked soil treatment, there was one pot that had no seeds germinate. One plant from another spiked soil treatment pot that had both seeds germinate was transplanted into the empty pot. In the Olinda Park treatment, three pots had no seeds germinate. Plants from other Olinda Park pots were transplanted into those empty pots. In the control treatment, only one pot had no seeds germinate, and one plant from another

control pot was transplanted over. Pots in all treatments were thinned down to one plant per pot. Where thinning occurred, pots were visually assessed and an attempt was made to ensure a uniform plant size across all treatments.

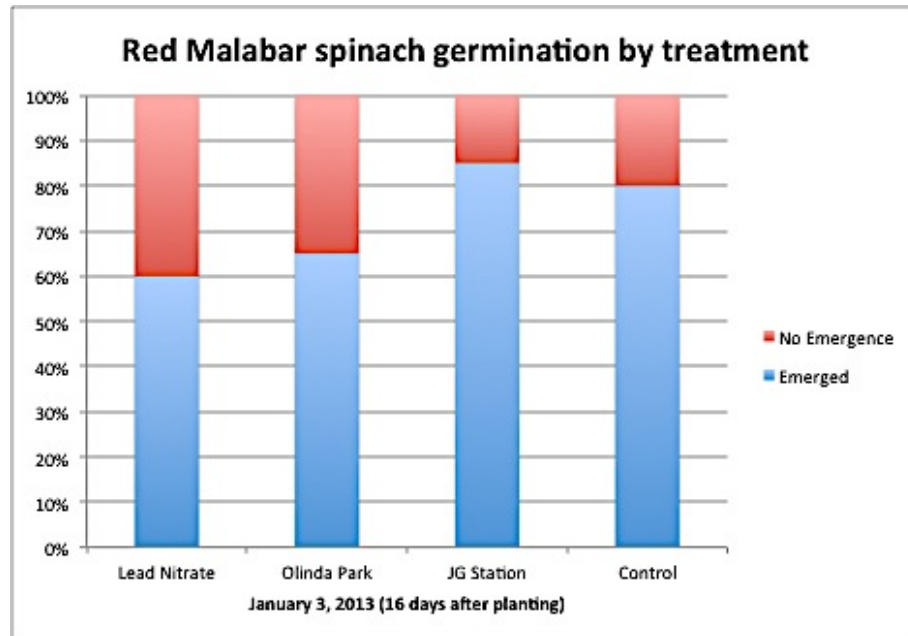


Fig 6. Percent of seed germination for red Malabar spinach (*Basella rubra*) by greenhouse treatment

#### *Plant Growth and Harvest*

There were obvious growth differences between the plants in each treatment. While the pots in the JG Shamrock/Supreme Gas Station treatment initially had the best seed germination rate, the plants within the pots appeared stunted as time went on. The stunted growth can also be seen in Table 4 based on the average dry weight for the JG Shamrock/Supreme Gas Station, which was lower than the dry weights for the other treatments. The leaves also were pointed upwards with a reddish purple tint in the veins of the leaves (Fig. 7a and Fig. 7b).



Fig 7a.



Fig 7b.

Fig 7a and 7b. Example of plant toxicity from JG Shamrock/Supreme gas station showing stunted plant growth, purple veins, and upturned leaves compared to the control treatment (January 30, 2013).

Plants in the lead nitrate and control treatments appeared to grow at comparable rates and visually looked similar. Growth of plants in the Olinda Park treatment varied, with some growing comparable to the control treatment, and others appeared stunted (Fig. 9). This can be seen from the larger standard deviation for the average dry weight of the plants in Olinda Park (Table 4). Three of the plants in the Olinda Park treatment also showed upturned leaves and red-purple veins on the leaves. The other seven plants appeared to grow well, growing larger than the control treatment.





Fig 8. Example of setup for plant treatments in hydroponic tanks in the greenhouse during greenhouse experiment



Fig 9. Example of growth differences of red Malabar spinach (*Basella rubra*) for plants in Olinda Park treatment



Plants from the JG Shamrock/Supreme Gas Station were harvested on January 30, 2013 because plants appeared to be in distress and it was estimated they would die before the other treatments reached the predetermined harvest characteristics of at least 3-4 large leave on each plant. The control and lead nitrate sites were harvested on February 6, 2013 and on February 7, 2013 the Olinda Park treatment was harvested. The plants were harvested intact with the roots, and any leaves that fell off or broken roots were salvaged. It was observed that plants grown in the treatments containing Pb had roots growing predominantly along the edge of the pot with fewer roots found in the bulk soil, as if the plant was trying to avoid contact with Pb in the soil.

After harvest plants were separated into shoots and roots and weighed. Roots and the edible portion of the plant (leaves and shoots) were analyzed separately to compare Pb content through the plant.



Fig 10a.



Fig 10b.

Fig 10a. Oven dried plant tissue, separated into shoots and roots being weighed

Fig 10b. Mill used to grind oven dried plant tissue before digestion and ICP analysis

### *Plant Tissue Analysis*

The results of the ICP-OES analysis of the Pb concentrations in the shoot and root tissues can be seen in Table 4, along with the average dry weight for the entire plant in each treatment.

Greenhouse Treatment	Average Pb Concentration in mg/kg (shoot tissue)	Average Pb Concentration in mg/kg (root tissue)	Average dry weight in g (whole plant)
Control	16 ± 7	6 ± 6	2.1 ± 0.7
JG Shamrock/Supreme Gas Station	62 ± 9	483 ± 38	0.7 ± 0.8
Olinda Park	315 ± 348	1,353 ± 227	2.2 ± 1.9
Lead Nitrate	633 ± 418	4,824 ± 1,613	2.8 ± 0.7

Table 4. Average Pb concentrations in the shoot tissue (mg/kg), average Pb concentrations in the root tissue (mg/kg), and average dry weight of the whole plant (g) for each treatment in the greenhouse experiment

The ANOVA comparison revealed statistically significant differences between the averages of total Pb concentration in the aboveground shoot tissue, as shown in Figure 11. The average concentration in each treatment was significantly different from the averages of the other treatments, with the highest average Pb concentration in the lead nitrate treatment, and the lowest average Pb concentration in the control treatment.

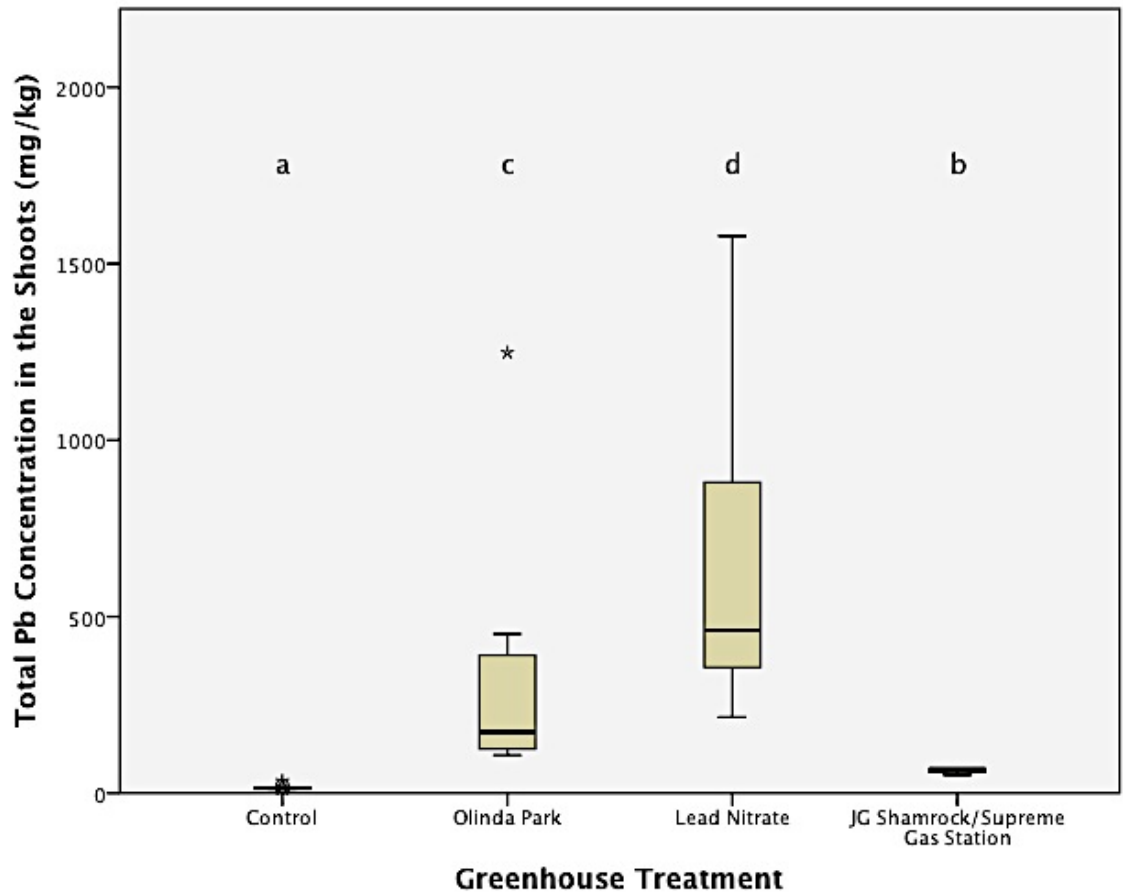


Fig 11. Average total lead (Pb) concentrations in edible shoot tissue of red Malabar spinach (*Basella rubra*) in each of the greenhouse treatments

The ANOVA comparison of the plant tissue revealed statistically significant differences between the averages of total Pb concentration in the root tissue, as shown in Figure 12. The average concentration in each treatment was significantly different from the averages of the other treatments, with the highest average Pb concentration in the lead nitrate treatment, and the lowest average Pb concentration in the control treatment. Figure 12 shows the comparison between the Pb average concentrations.

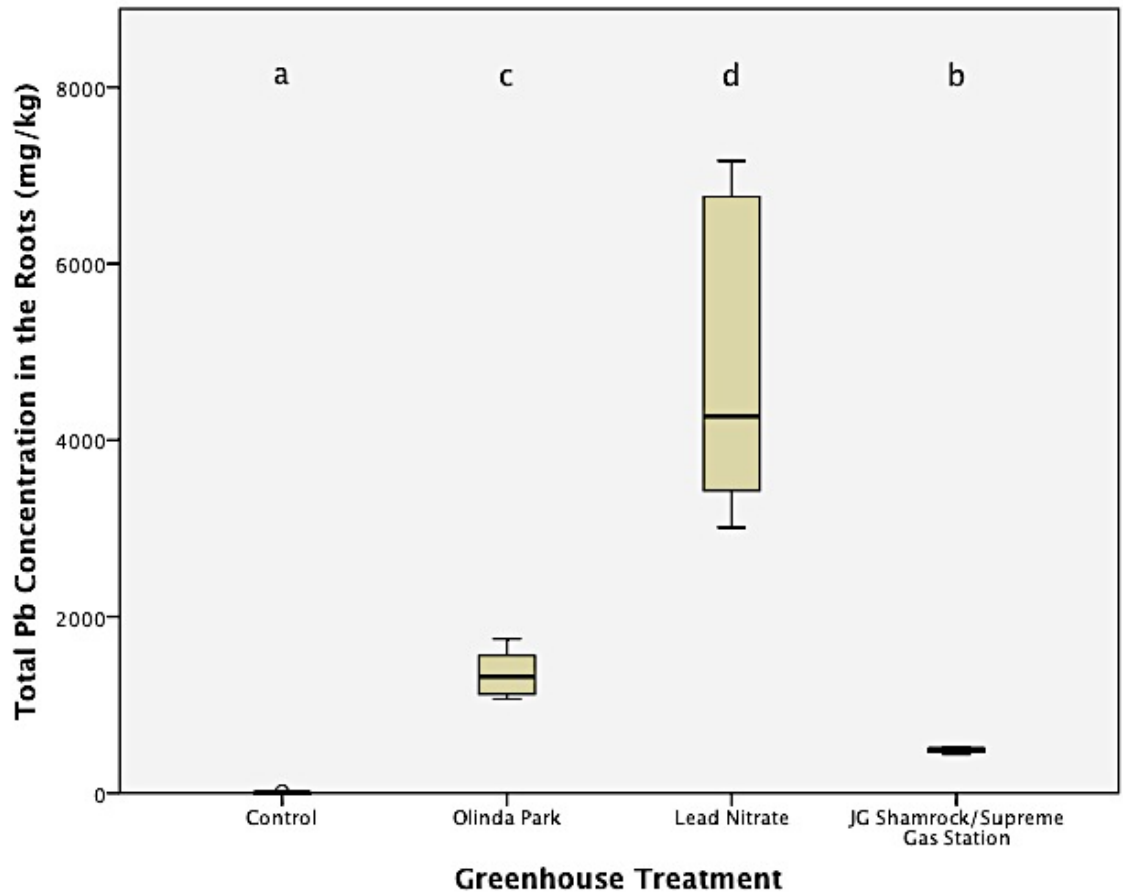


Fig 12. Average total lead (Pb) concentration in the root tissue of red Malabar spinach (*Basella rubra*) for each greenhouse treatment

A paired t-test was performed between the Pb concentrations in the shoot tissue and the Pb concentrations in the root tissue, to determine if the differences between the concentrations in the parts of the plant were significantly different from each other. According to the results from the t-test, the Pb concentrations in the shoot tissues were significantly lower than the Pb concentrations in the root tissue, with a difference in means of approximately  $m = -1,619.9$  ppm, making the concentrations in the roots six times higher than the concentration in the shoots.

## **CHAPTER IV: Discussion**

### *Soil Lead (Pb) Levels*

This study was conducted to investigate the presence of Pb in the neighborhood of Liberty City, and assess the suitability of soil for gardening. This is especially true for the site at Northwestern Senior High School given the partnership existing to build a garden there between Florida International University and the high school. After analysis of the soil at Northwestern Senior High School, it was determined that none of the soil cores showed soil Pb levels over the EPA limit of 400 mg/kg. Cores from the high school were not shown to significantly differ statistically from the cores at Olinda Park, JG Shamrock/Supreme gas station and the control organic farm. The statistical results are slightly misleading, especially considering that Olinda Park and JG Shamrock/Supreme gas station had cores that far exceeded the EPA 400 mg/kg soil Pb limits (U.S. Environmental Protection Agency, 2012). This is because of the fact that the ANOVA is averaging all of the soil cores for the site, and since the soil Pb levels in some cores were extremely low, it brought the averages down making them comparable to the high school and the organic farm. For example, the smallest core concentration at Olinda Park was 24.5 ppm, and the largest core concentration was 2,863.2 ppm. Since hot spots were observed at two sites, Olinda Park and JG Shamrock and Supreme Gas Station, further sampling and analysis of the soil would be necessary to try and pin point the location and spatial scope of the hot spots to get a better idea of which areas post the largest threat for Pb exposure. The site of the high school is estimated to be safe since all soil cores were below 400 ppm at the site for the proposed organic garden. However, since hotspots did exist at the other two sites in Liberty City, further sampling and analysis would be

necessary to identify hot spots on the rest of the high school property as well. It is possible that the high school could contain hot spots where concentrations were much higher, but the sampling technique used did not detect them, since there was a lot of variability in concentrations over the areas sampled. A possible sampling technique that would be more sensitive to the variability would be the EPA method for sampling suspected contaminated sites.

### *Soil Characterization*

The Mehlich 3 and sodium bicarbonate extractions were performed to get an estimation of the available nutrient content at each site in Liberty City. This information could be useful to groups wishing to start a garden in the area; because it would provide a baseline so appropriate fertilizers and soil additions could be chosen to adequately grow a garden, depending on what plants will be grown. The nutrient content in each of the soils did seem to be similar in Liberty City, differing from the control organic farm. It was expected the organic farm would contain more nutrients and the sites in Liberty City would be more nutrient poor since none of them are fertilized the way the organic farm would be. This was observed to not always be the case, depending on the individual nutrients.

### *Availability of Soil Lead (Pb) to Plants*

Within all of the greenhouse treatments, the Pb present within the soil was available to plants and accumulated within the Malabar spinach tissue. The Pb concentrations were significantly higher in the root tissue than in the shoot tissue,

indicating the Pb stayed mostly in the roots, but a portion of that concentration was able to move into the shoot tissue and accumulate there. Given the concentrations were extremely high in roots, even though a portion of that moved into the shoot tissue, it would prove to be a significant pathway for Pb exposure if someone was to eat the shoot tissue of the plants grown in any of the treatments, except the control treatment. As expected, the concentrations in the control treatment were low and would not pose a significant risk for Pb exposure. The potential for exposure to harmful concentrations would be largest at the Olinda Park and JG Shamrock/Supreme Gas Station, since those sites contained cores with concentrations much higher than the control treatment, and above the EPA limit.

The highest concentrations in both the root and the shoot tissue were seen in the lead nitrate treatment. This was to be expected, since soil ageing is known to have a significant effect on the binding of heavy metals, such as Pb, into the soil. The longer the contamination has been allowed to age in the soil, the less available it would be for accumulation within plant tissue. Even though the concentration of Pb within the lead nitrate treatment was not higher than any of the other Pb treatments, the Pb had only been ageing within the soil for approximately six weeks. This would allow the Pb to be more mobile, readily accumulating in the root and shoot tissues of the Malabar spinach over the course of the greenhouse study. The Pb present within the soil in Liberty City, though the exact amount of time the Pb has been in the soil is unknown, it can be estimated the Pb is not a recent contamination event.

### *Estimated Risk of Lead (Pb) Exposure*

Given the results of the soil Pb analysis, there does exist a possible risk of Pb exposure and subsequently Pb poisoning to residents who come in contact with the hot spots identified in Olinda Park and JG Shamrock/Supreme gas station. By doing a ratio of the soil Pb averages, when the average of the control organic farm (148 mg/kg) is compared to the average of only hot spots in Olinda Park (1,513 mg/kg) the risk is ten times higher at Olinda Park than the organic farm. When the average of the hot spot in JG Shamrock/Supreme gas station (6,566 mg/kg) are compared to the organic farm, the risk is forty-five times higher. It is therefore recommended that residents do not have contact with the soil in both of the sites until further analysis could be done to further map the hotspot locations, and remediation actions taken at those hotspot sites. The soil Pb concentrations are high enough in the hotspots, that effects could be experienced from exposure to the Pb in the soil, especially if soil is inhaled or ingested.



## **CHAPTER V: Conclusion**

There does exist in Liberty City, Florida, significant risk of exposure to Pb through both the primary and secondary pathways. The primary pathway being the ingestion or inhalation of contaminated soil particles, and the secondary pathway being ingestion of foods grown in contaminated soils that have accumulated Pb within the edible shoot tissues. All of the values for Pb concentrations in the soil and edible tissues of red Malabar spinach would contribute to the lead burden in the body, and potentially add up to produce symptoms of lead poisoning. The Pb concentration values were highest at the Olinda Park and JG Shamrock/Supreme Gas Station sites; therefore the potential for exposure is highest at those sites. When the average soil Pb concentrations were compared to the control site, the average Pb concentration of the hotspots at Olinda Park was ten times higher, and the average Pb concentration of the hotspots at JG Shamrock/Supreme Gas Station was forty-five times higher. Similarly, when the average shoot Pb concentrations were compared to the control treatment, the average shoot Pb concentration at Olinda Park was 20 times higher, and the average shoot Pb concentration at JG Shamrock/Supreme Gas Station was 4 times higher.

This risk is important to acknowledge and keep in mind when considering an urban or residential gardening project within urban ecosystems. Since there has been an increasing trend in the popularity of community gardens within cities, it would be recommended in Liberty City to take alternative measures to ensure safety for residents wishing to participate in the gardening movement. For severely contaminated sites, such as Olinda Park, remediation would be recommended to ensure residents, especially children, would not be harmed by the elevated concentrations of Pb. It has been observed

that Miami-Dade County has started the remediation of Olinda Park. It is also important to properly label and fence off highly contaminated sites. Even though Olinda Park was fenced off and labeled with signs saying “contaminated area”, it was observed that the fence put up to protect people from going inside was cut and pulled open, allowing anyone access to the area. For this reason, community education programs should be initiated in areas that have a site such as Olinda Park, so residents can understand what the contamination area represents and what the dangers are.

Similarly, sites such as JG Shamrock/Supreme Gas Station, which was a brownfield site, should be labeled and residents should be informed and educated as to what a brownfield site is and what potential risks there are. It was observed at the site that there was a sign labeling the site as a brownfield, but the sign was so faded, it could only be read from directly in front of the sign. To anyone passing by, the sign would look blank and could easily be ignored. It has also been observed that children were seen playing at the site, since it appears to be an empty lot in the middle of the neighborhood. This increases the risk of children being exposed to not only Pb, but also other unknown contaminants since the site used to be a gas station, is a brownfield, and has not been remediated.

In urban areas where residents wish to start urban gardening programs, but are unsure of the contaminants that could be present within the soil, the best recommendation is to instead build raised gardening beds that are lined with landscaping fabric to limit the contact between the soil in the bed and the contaminated soil underneath (Clark et al., 2008). This solution would not completely address the primary pathway for Pb exposure,

but would limit the secondary pathway of consuming vegetables that have accumulated contaminants in their tissues.

When neighborhoods or local governments are planning remediation projects such as excavation of a site or phytoremediation, it is important to include a monitoring component since there is the possibility of recontamination from other sites in the area that are also contaminated. This would include wind-transport of soil particles contaminated with Pb, or atmospheric depositions. Remediation requires maintenance in order to limit exposure and ensure the safety of the residents and the food they grow.

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